Charge Asymmetry Dependency of π/K Anisotropic Flow in UU and AuAu $\sqrt{S_{NN}}$ 200GeV Collisions at STAR

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STAR

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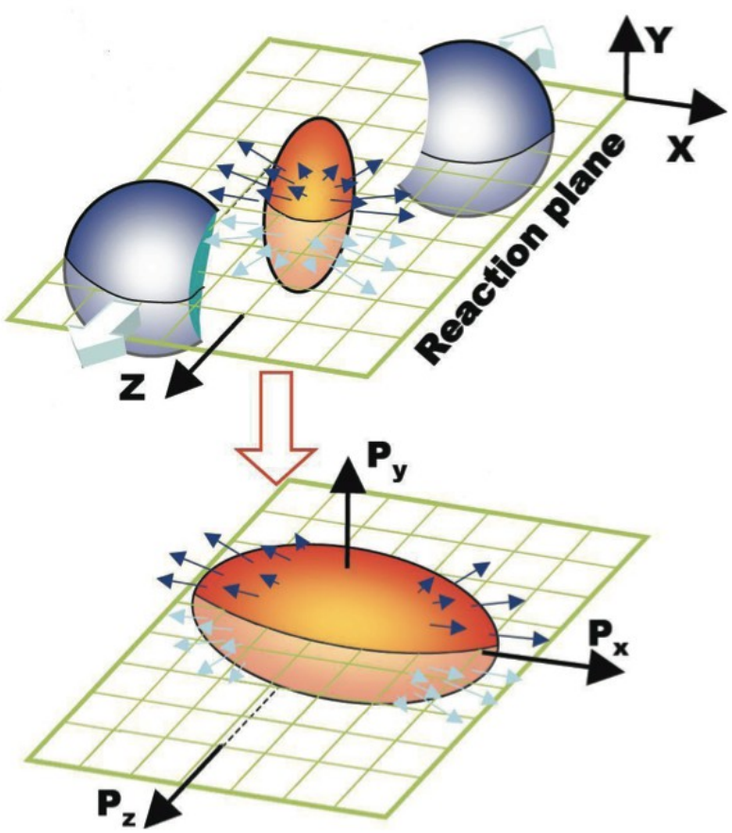
Anisotropic Flow



$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}(1 + \sum_{n=1}^{\infty} 2v_n cos[n(\phi - \Psi_r)])$$

$$v_n = \langle \cos n(\phi - \Psi_R) \rangle$$

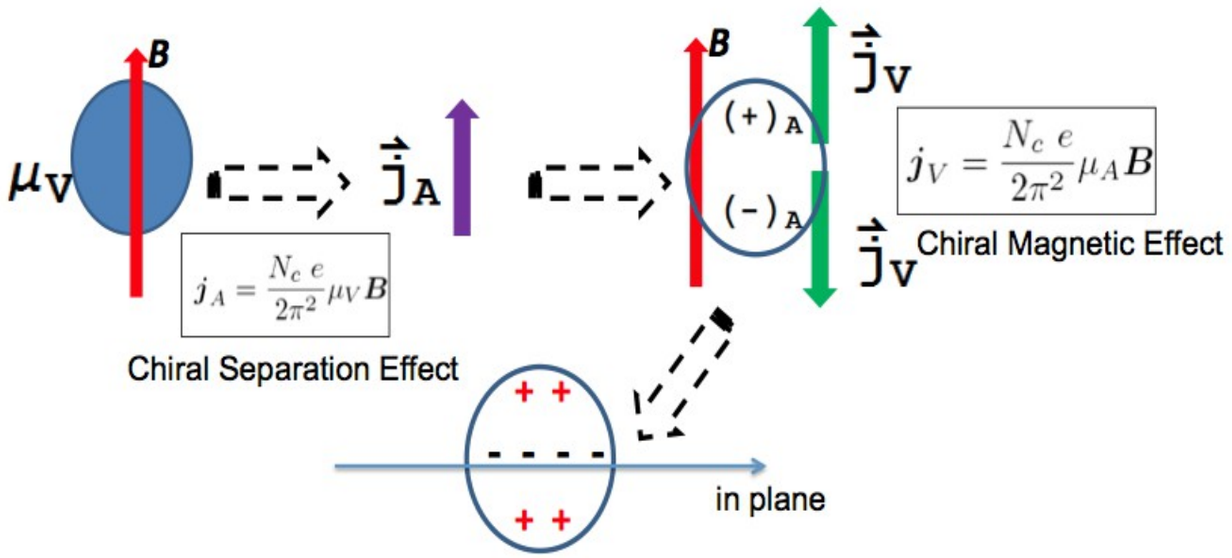
- The elliptic flow, v_2, which characterizes the ellipse shape of the azimuthal anisotropy, is the second order harmonic coefficient.
- Third harmonic coefficient, v_3, known as triangular flow, is a new tool to study initial-state fluctuations.

- Flow describes the azimuthal momentum space anisotropy of particle emission from non-central heavy-ion collisions in the plane transverse to the beam direction
- A measurement of flow provides access to the fundamental thermalization time scale and many more things in the early stages of a relativistic heavy-ion collision

Chiral Magnetic Wave

- Chiral Magnetic Wave (CMW), composed by the waves of the electric and chiral charge densities coupled by the axial anomaly, stems from the interplay of Chiral Magnetic Effects(CME) and Chiral Separation Effects (CSE)

- CMW at finite baryon density can induce the electric quadrupole moment, which may lift the degeneracy between the elliptic flows of positive and negative pions leading to $v_2(\pi+) < v_2(\pi-)$



$$\frac{\mathrm{d}N_\pm}{\mathrm{d}\phi} = N_\pm\left[1 + 2v_2\cos(2\phi)\right]$$
$$\approx \bar{N}_\pm\left[1 + 2v_2\cos(2\phi) \mp A_{ch} r\cos(2\phi)\right]$$

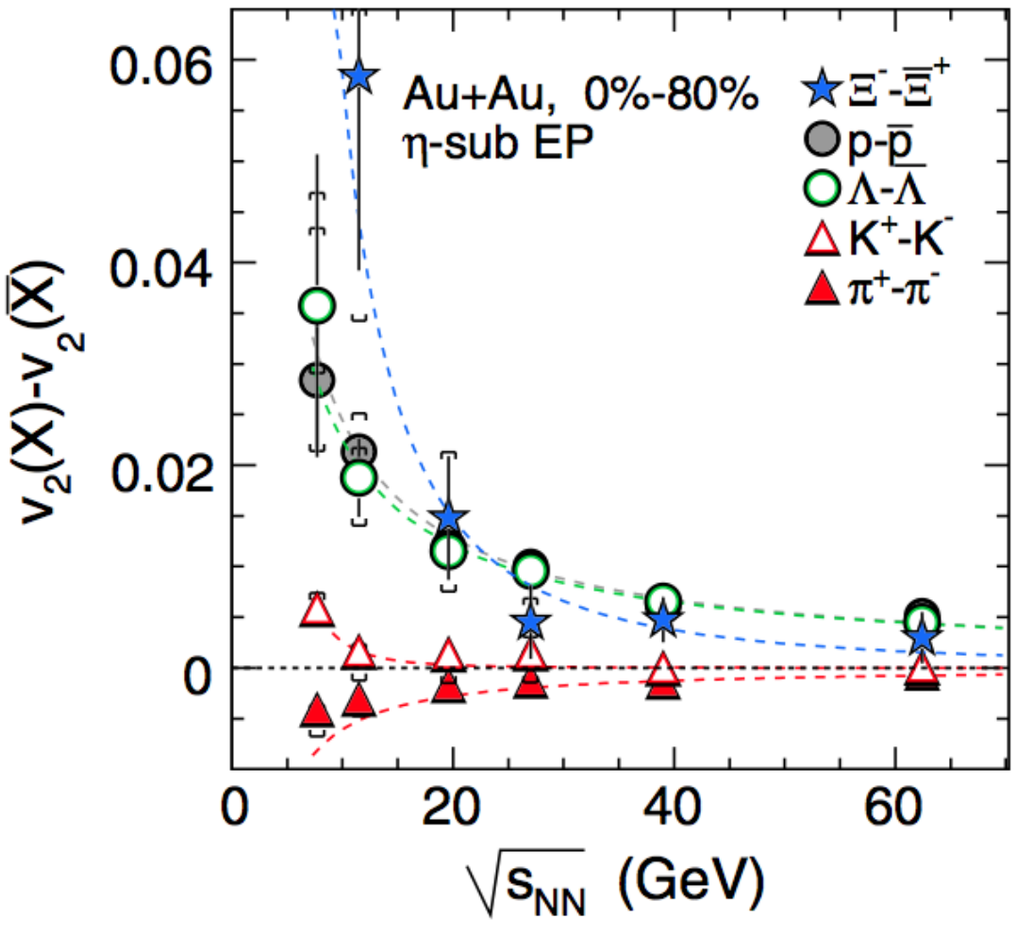
$$\Delta v_2^{\mathrm{CMW}} \equiv v_2(\pi^-) - v_2(\pi^+) \approx r A_\pm$$

$$A_{ch} = \frac{N_+ - N_-}{N_+ + N_-}$$

$$r = 2q_e/\bar{\rho}_e$$

Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. 107, 052303 (2011)

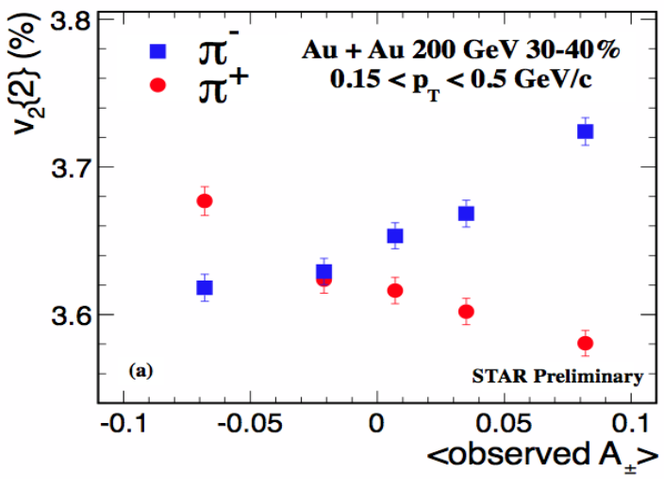
Flow Difference

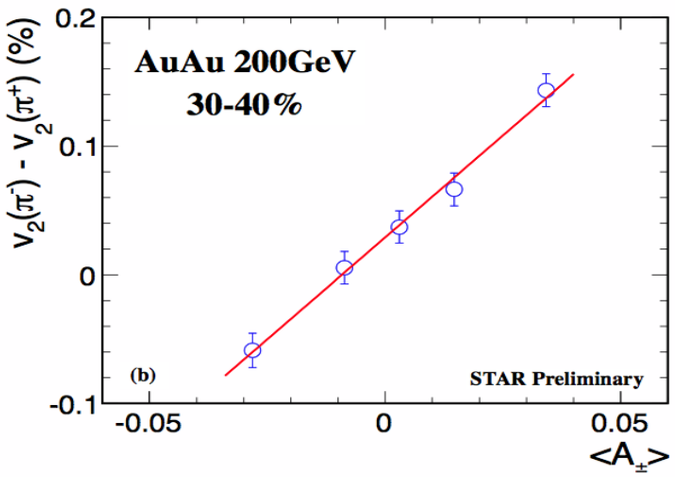


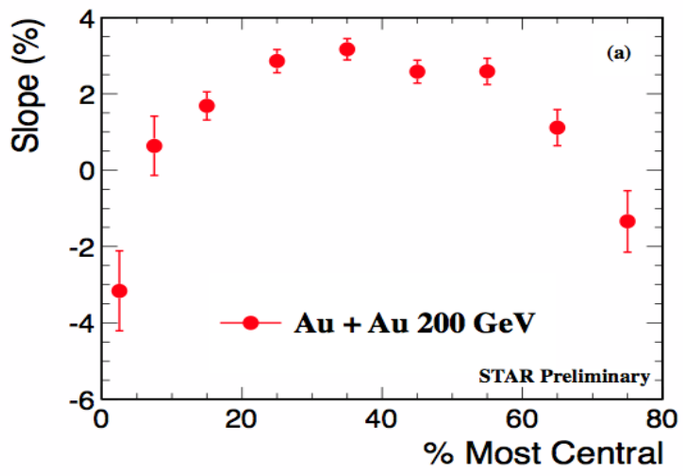
A beam-energy-dependent difference of v_2 between particles and corresponding antiparticles has been observed

L. Adamczyk et al. (STAR Collaboration) Phys. Rev. Lett. 110, 142301 (2013)

Flow Difference, in more detail







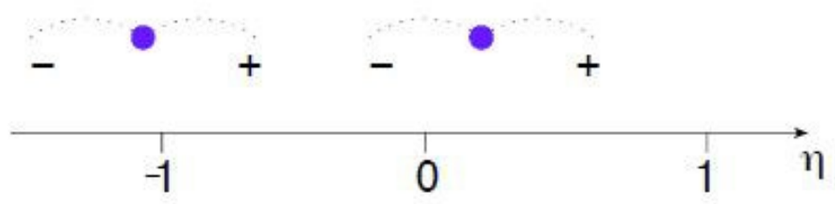
- In AuAu collisions, v_2 difference between π+ and π- at low p_T is found to be proportional to A_{ch} [1]
- This observation is consistent with the prediction of the existence of Chiral Magnetic Wave. The trend of the slope of $\Delta v_2(\pi)$ is also consistent with CMW calculation

[1] Hongwei Ke (for the Star Collaboration) 2012 J. Phys.: Conf. Ser. 389 012035

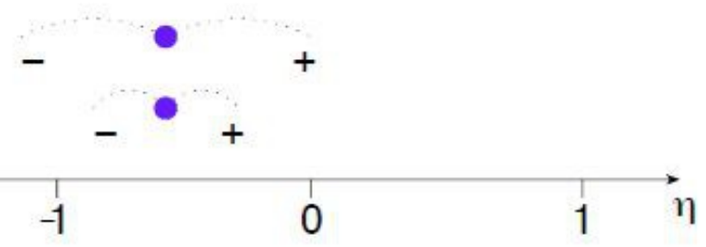
An Alternative Explanation

$$\langle v_2^+ \rangle_A \approx \langle v_2^+ \rangle_{A=0} - \alpha A \left[\langle v_2^+ \rangle_{A=0} - \langle v_2^+ \rangle_{\text{asym}} \right] \qquad \langle v_2^- \rangle_A \approx \langle v_2^- \rangle_{A=0} + \alpha A \left[\langle v_2^- \rangle_{A=0} - \langle v_2^- \rangle_{\text{asym}} \right]$$

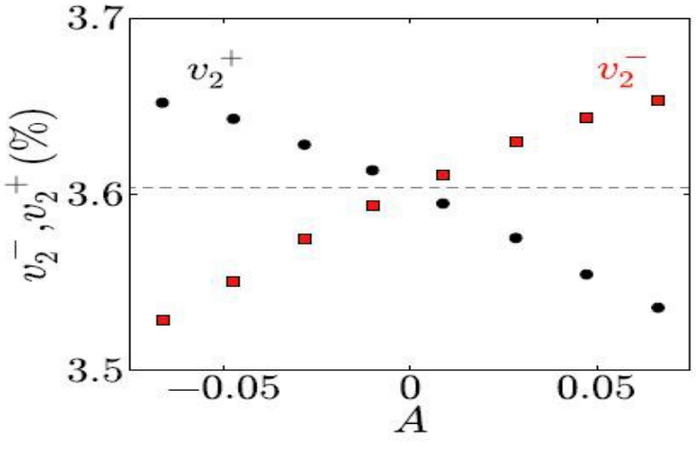
As long as $\left[\langle v_2^+ \rangle_{A=0} - \langle v_2^+ \rangle_{\text{asym}} \right]$ has a correlation with η and p_T, we will see this linear relationship between v_2 and A_{ch} [1]

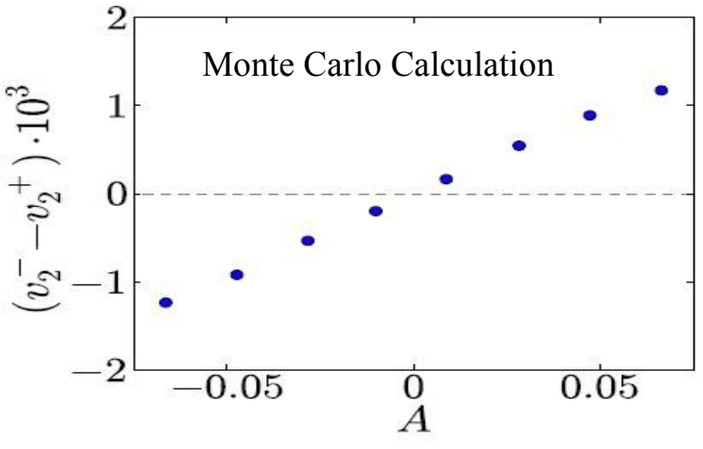


Rapidity window only including positive π at A>0, will lead to decrease positive π v_2 and increase negative π v_2



p_T window only including high p_T cluster at non-zero A, will lead to $\langle v_2 \rangle_{asym}$ smaller than $\langle v_2 \rangle_{A=0}$





It is suggested that a similar effect for higher harmonics v_3 can be observed according to above two mechanisms, and should be smaller by a factor of 3 compared to v_2

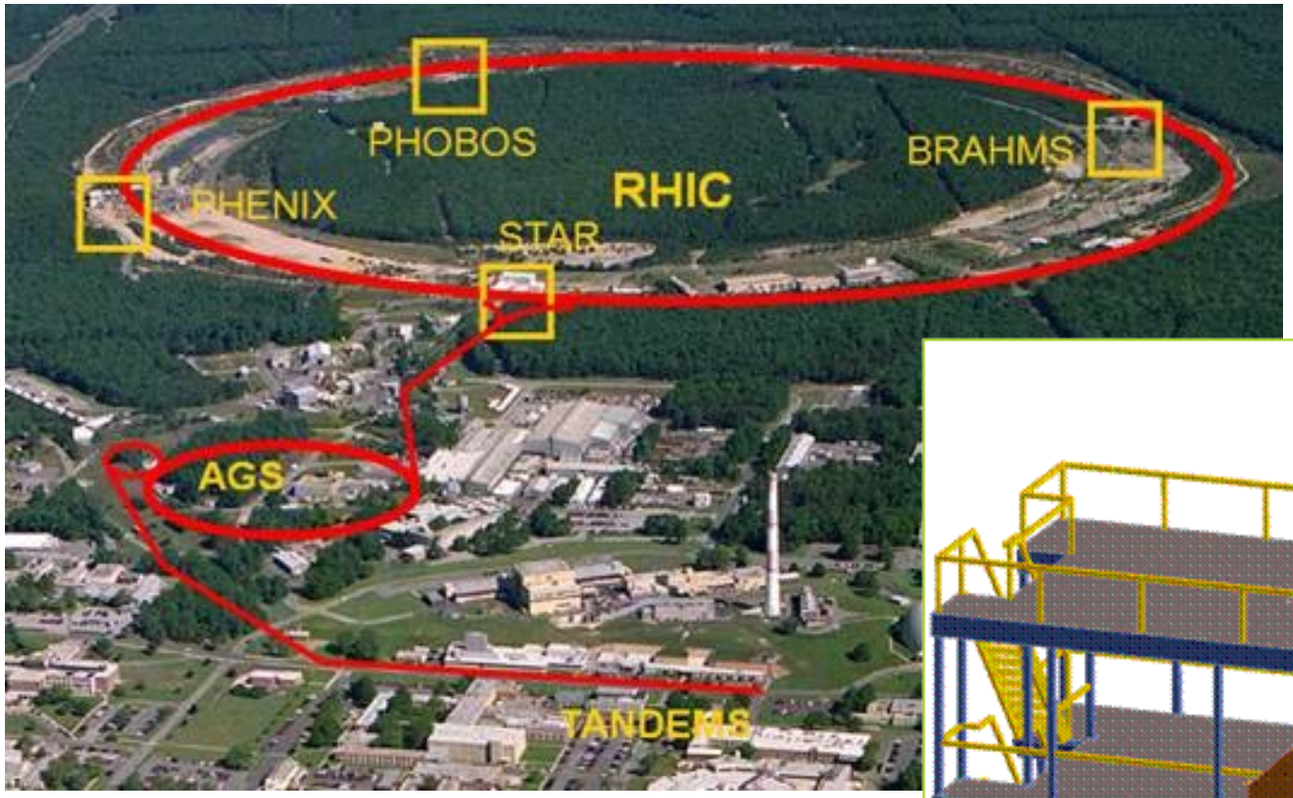
[1] A. Bzdak, P. Bozek, arXiv:1303.1138v2

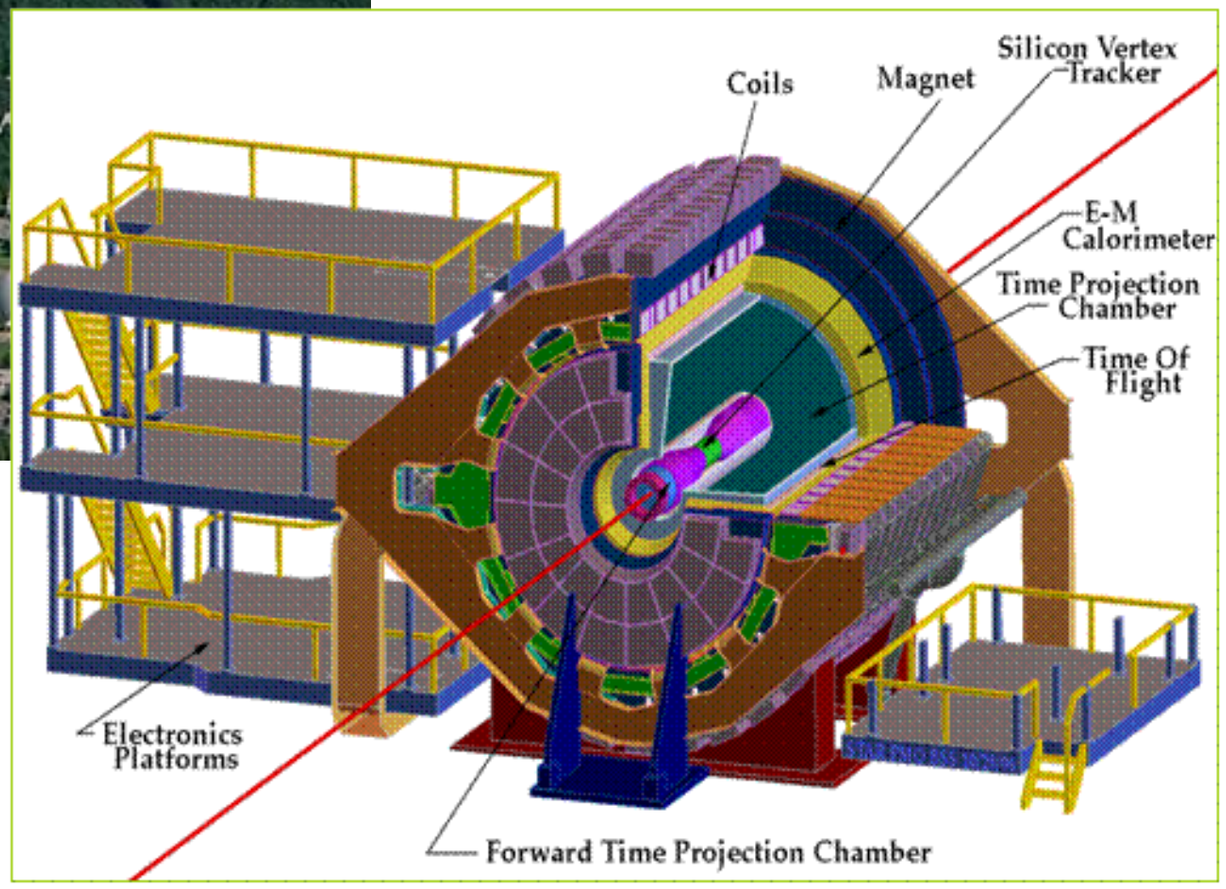
Motivation

- The measurement of $v_3(\pi)/\Delta v_3(\pi)$ as a function of A_{ch} may give evidence of CMW or other explanation
- UU collisions serve as a consistency check due to their special geometry deformation
- It is suggested that the slope of $\Delta v_2(A_{ch})$ for kaon[1] may be different

[1] Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. 107, 052303 (2011)

RHIC - STAR





Nuclear Instruments and Methods in Physics Research Section
Volume 499, Issues 2–3, Pages EX1-EX4, 235-880 (1 March 2003)
The Relativistic Heavy Ion Collider Project: RHIC and its Detectors

Dataset, Event / Track Selection

Event Selection

- Run10 AuAu 200GeV ~ 328M MinBias
- Run11 AuAu 200GeV ~ 555M MinBias
- Run12 UU 193GeV ~ 643M MinBias
- $|V_z| < 30$ cm
- $|V_r| < 2$ cm

Charged Asymmetry

- Charged Particle
- $0.15 < p_T < 12$ GeV/c
- $|\eta| < 1$
- Exclude (anti)proton with $p_T < 0.4$ GeV/c

Flow

- Primary Track with DCA < 1cm
- Pion identification $|n\sigma_\pi| < 2$ and $0 < m^2 < 0.1$
- Kaon identification $|n\sigma_K| < 2$ and $0.15 < m^2 < 0.35$
- $0.15 < p_T < 0.5$ GeV/c
- $|\eta| < 1$

Flow Calculation (Q-Cumulants)

1. Flow vectors:

$$\text{Reference Particle (RP):} \quad Q_n \equiv \sum_{i=1}^{M} e^{in\phi_i}$$

$$\text{Particle of Interest (POI):} \quad p_n \equiv \sum_{i=1}^{m_p} e^{in\psi_i}$$

$$\text{RF \& POI:} \quad q_n \equiv \sum_{i=1}^{m_q} e^{in\psi_i}$$

η gap (0.3, 1.0) to subtract non-flow correlation

2. Two-particle Correlations:

$$\langle 2 \rangle = \frac{|Q_n|^2 - M}{M(M-1)}$$

$$\langle 2' \rangle = \frac{p_n Q_n^* - m_q}{m_p M - m_q}$$

3. Cumulants:

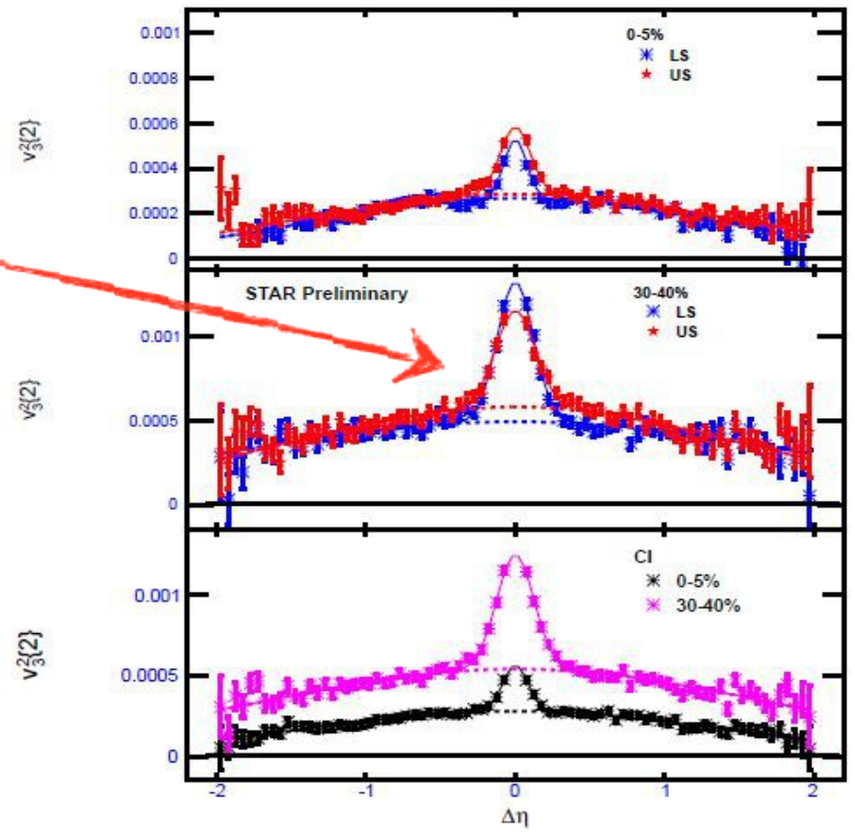
$$c_n\{2\} = \langle\langle 2 \rangle\rangle$$

$$d_n\{2\} = \langle\langle 2' \rangle\rangle$$

4. Flow estimation:

$$\text{Reference flow:} \quad v_n\{2\} = \sqrt{c_n\{2\}}$$

$$\text{Differential flow:} \quad v_n'\{2\} = \frac{d_n\{2\}}{\sqrt{c_n\{2\}}}$$



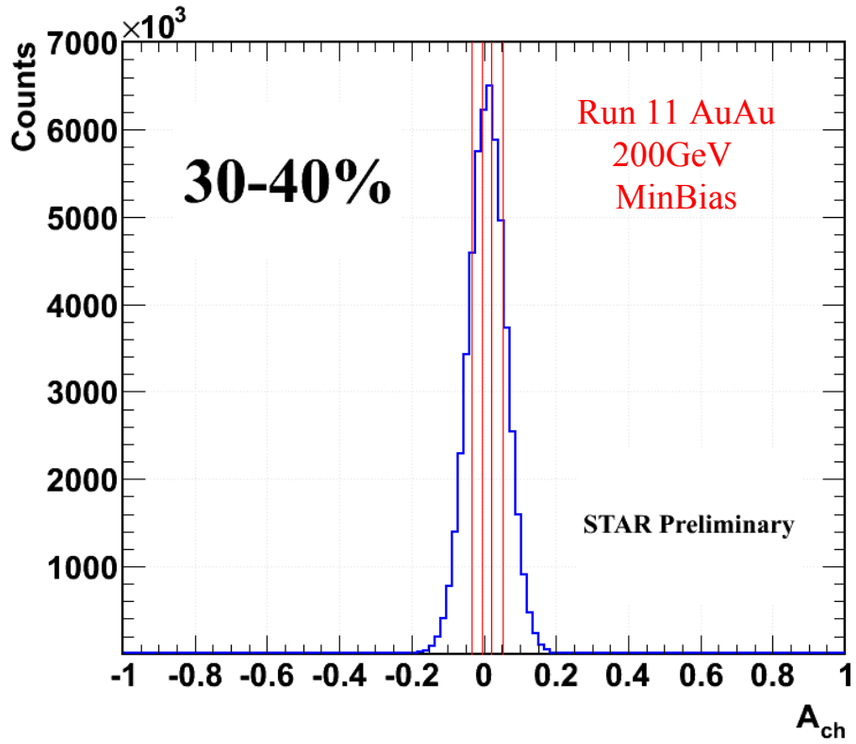
Yadav Pandit (for the Star Collaboration) 2013 J. Phys.: Conf. Ser. 420 012038

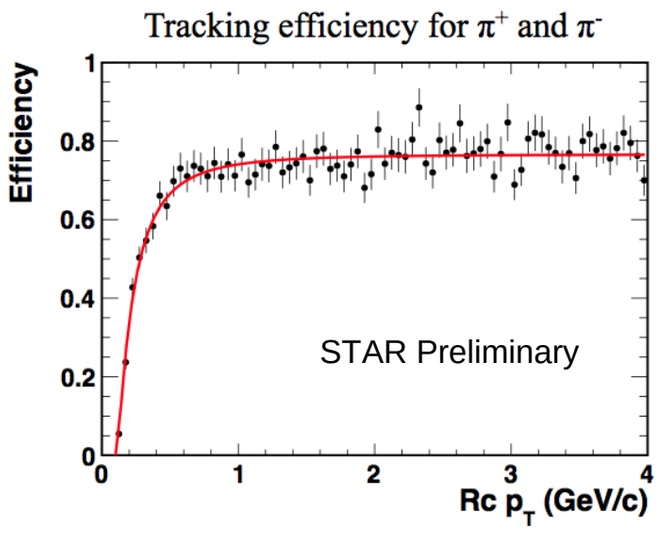
Charge Asymmetry

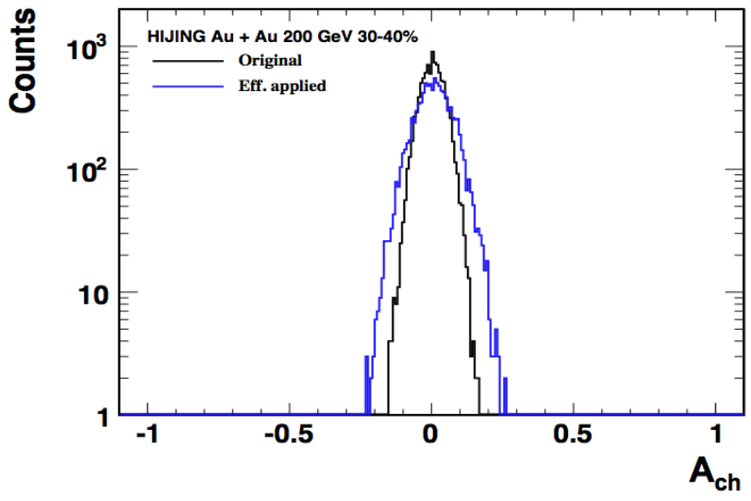
- observed A_{ch}

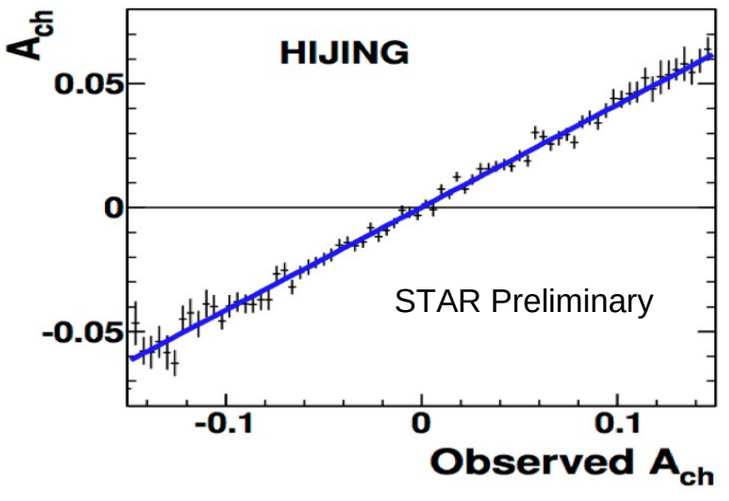
$$A_{ch} = \frac{N_+ - N_-}{N_+ + N_-}$$

- Each bin has the same number of events
- Use pion tracking efficiency as charged particle tracking efficiency
- Apply same cuts to calculate A_{ch} for Monte-Carlo and real data



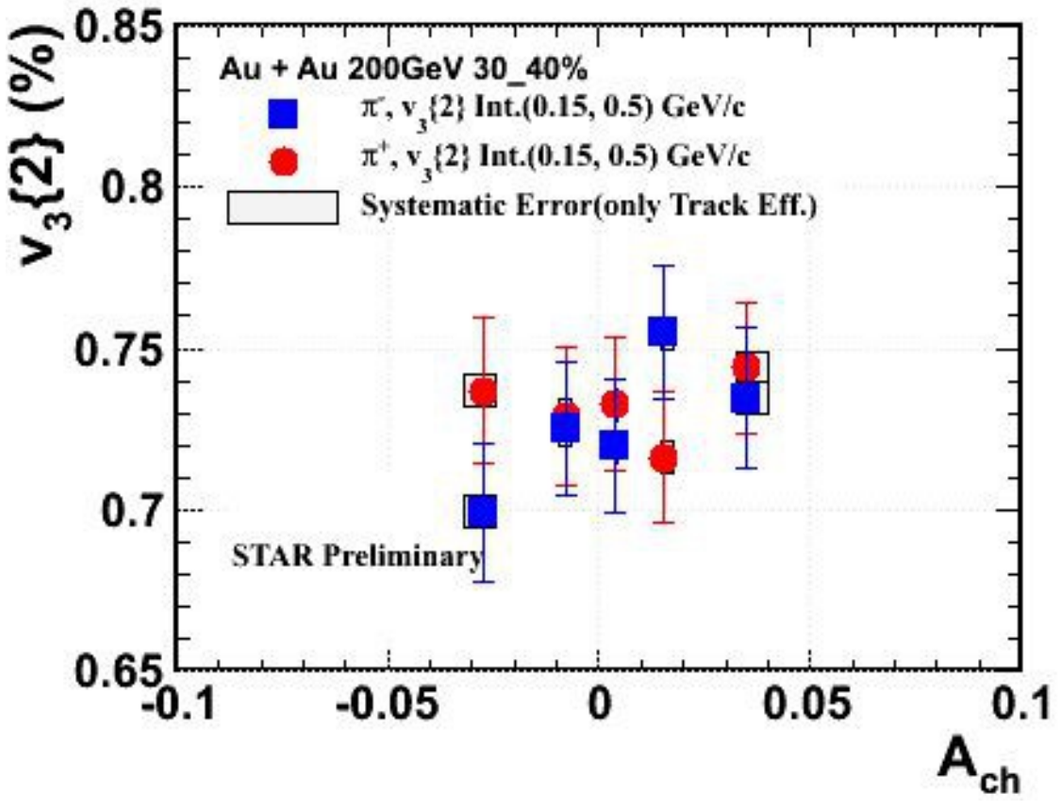


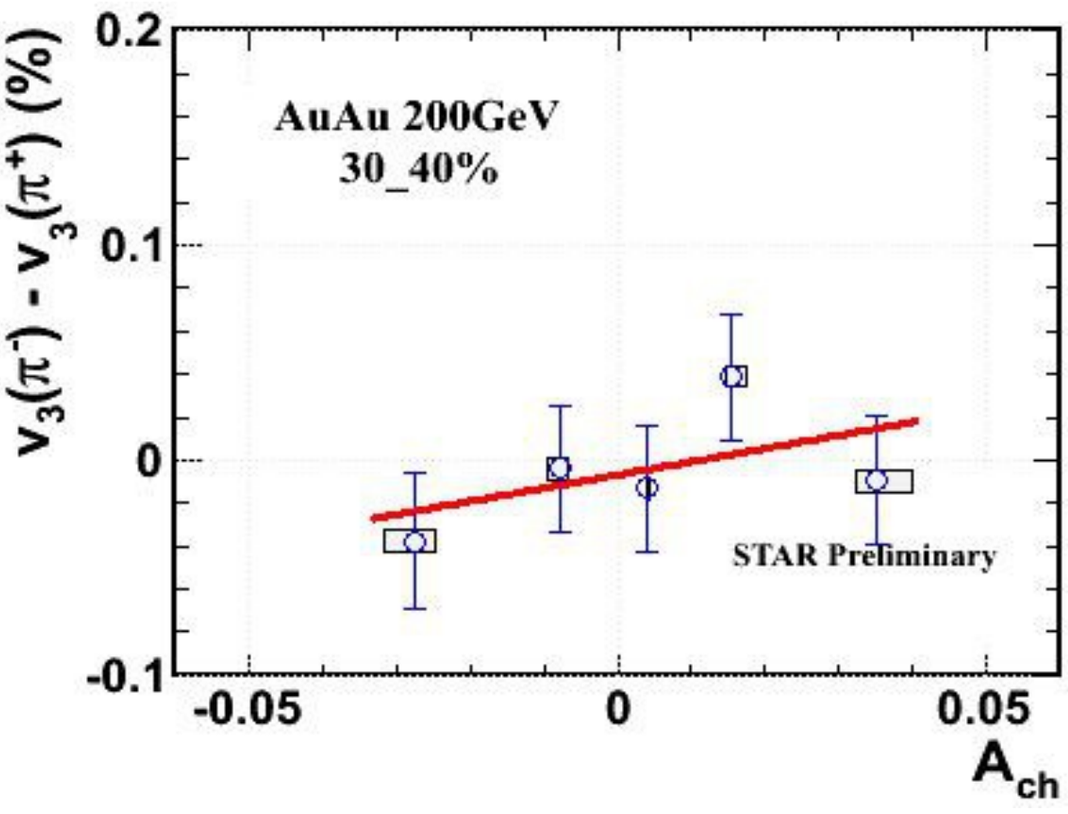




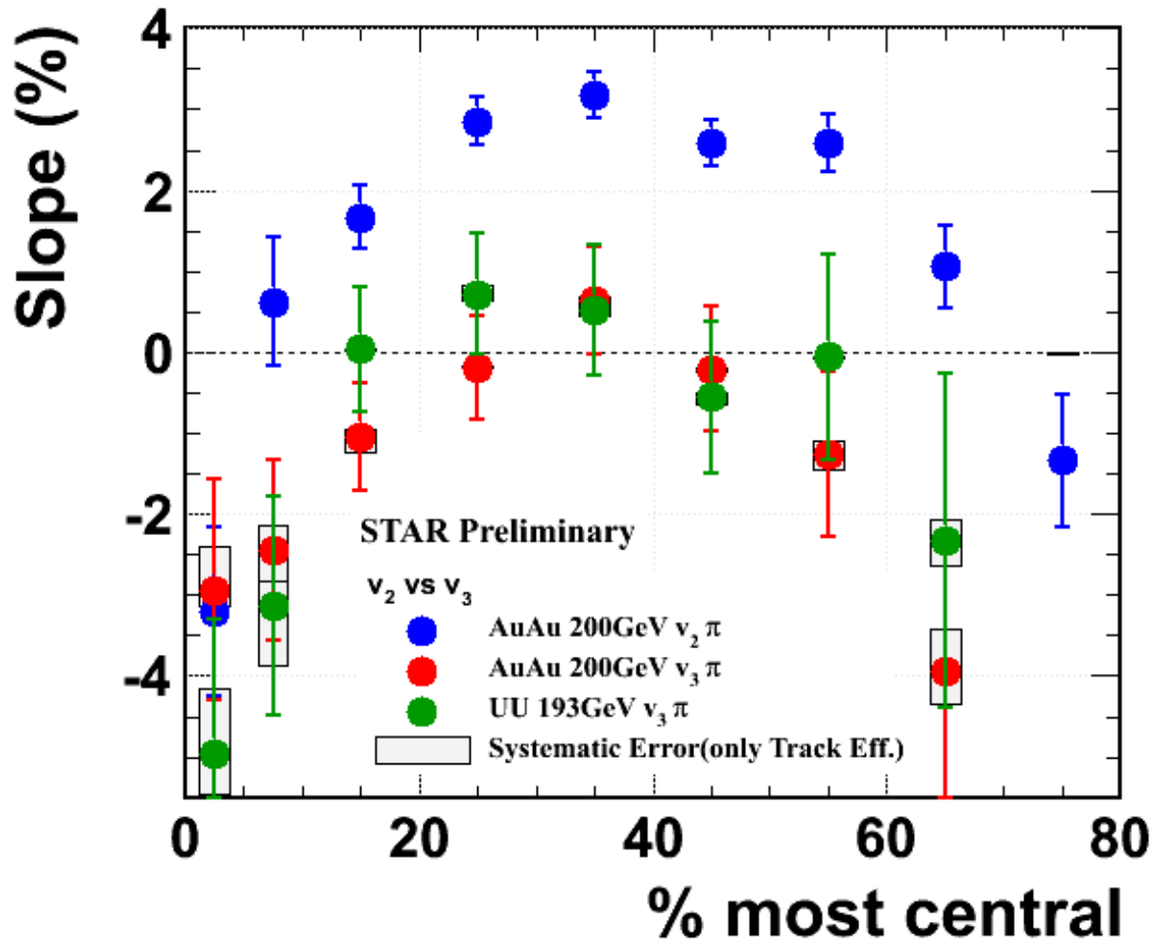
$v_3(\pi)/\Delta v_3(\pi)$ vs A_{ch} in AuAu Collisions

Background Experiment Analysis Results Summary



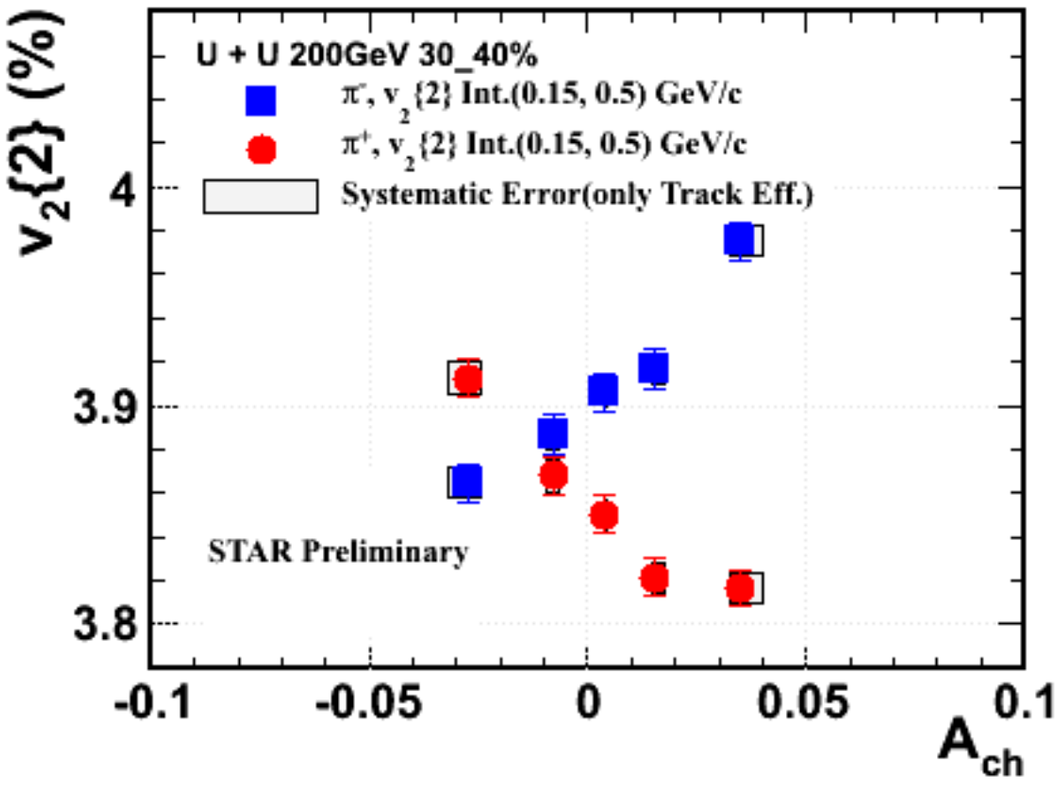


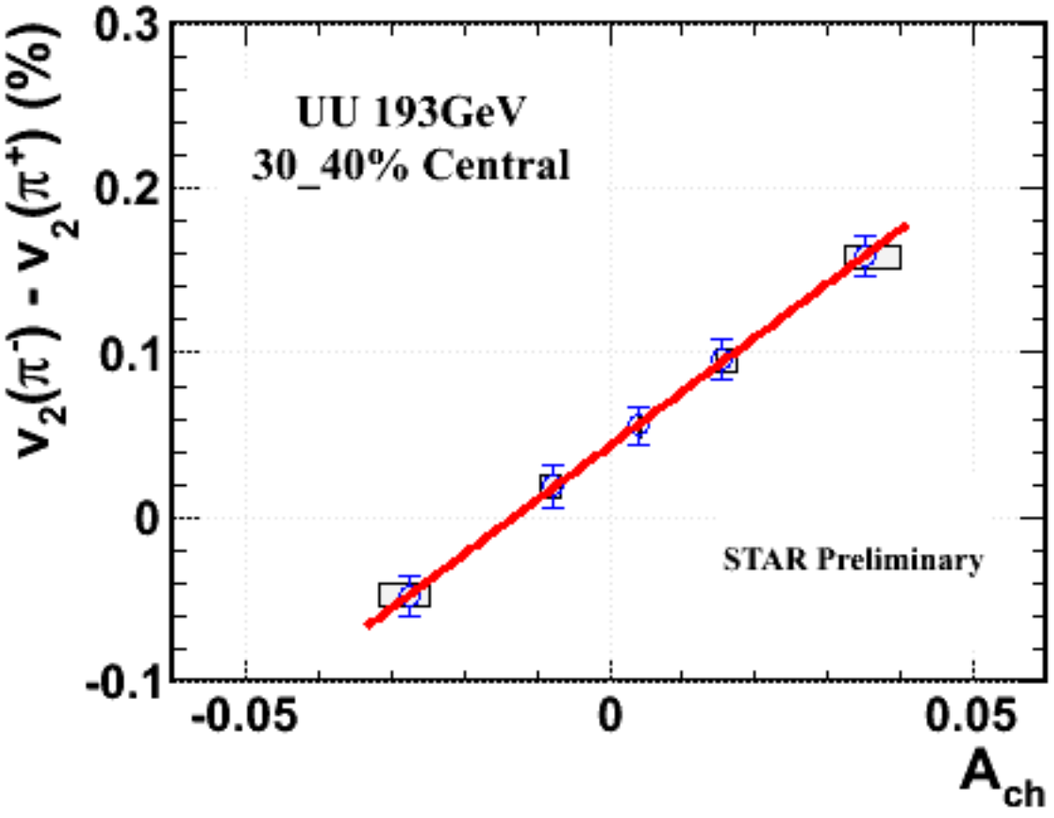
$\Delta v_3(\pi)$ Slope vs Centrality



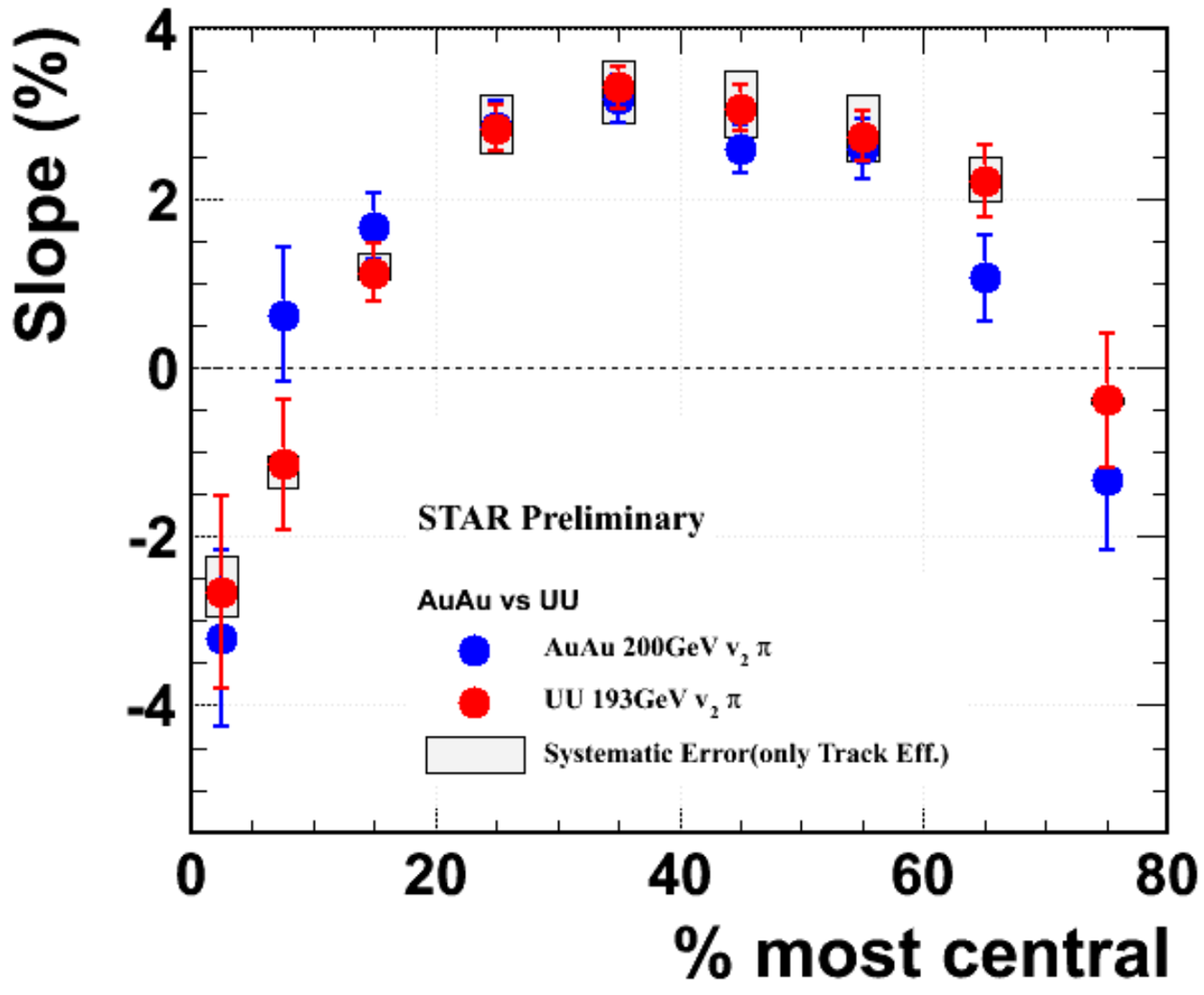
- The trend of $\Delta v_3(\pi)$ slope is similar to that of $\Delta v_2(\pi)$ slope
- Δv_3 slope is smaller than Δv_2 slope, and requires a quantitative comparison to test the acceptance window prediction

$v_2(\pi)/\Delta v_2(\pi)$ vs A_{ch} in UU Collisions



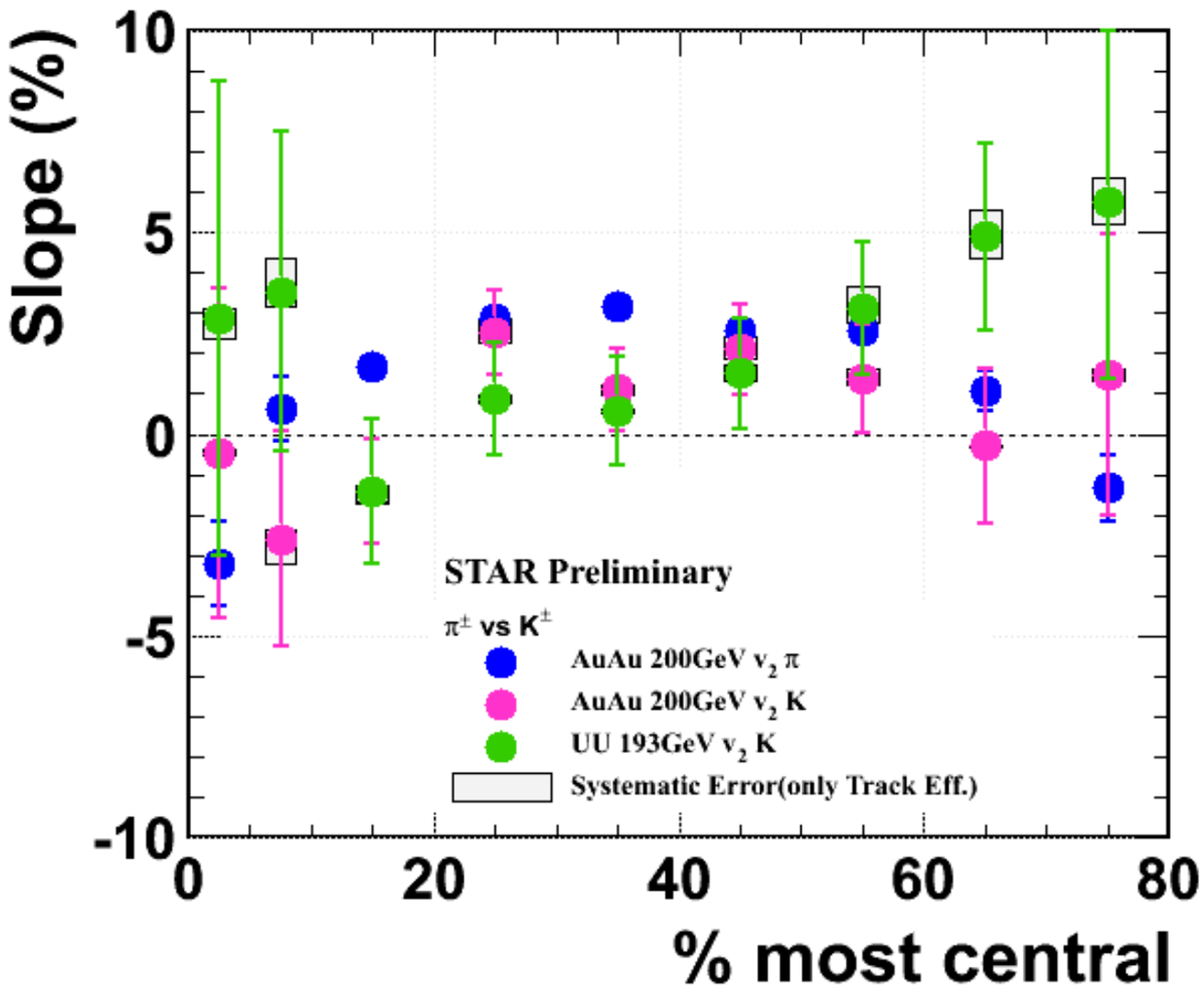


$\Delta v_2(\pi)$ Slope vs Centrality



The same linear relationship between v_2 of π and A_{ch} has been confirmed in MinBias, UU collisions

Δv_2(K) Slope vs Centrality



- It is suggested[1] that the slope of Δv_2 vs A_{ch} for kaon can be different from slople for pion
- More statistics needed for kaon

[1] Y. Burnier, D. E. Kharzeev, J. Liao and H-U Yee, Phys. Rev. Lett. 107, 052303 (2011)

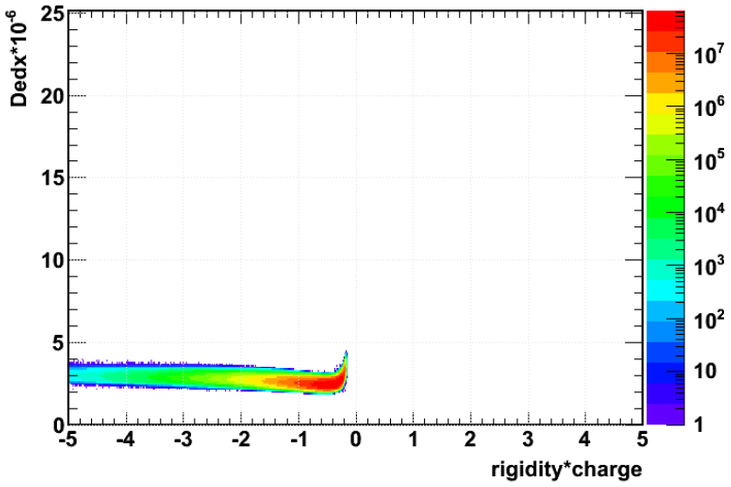
Summary

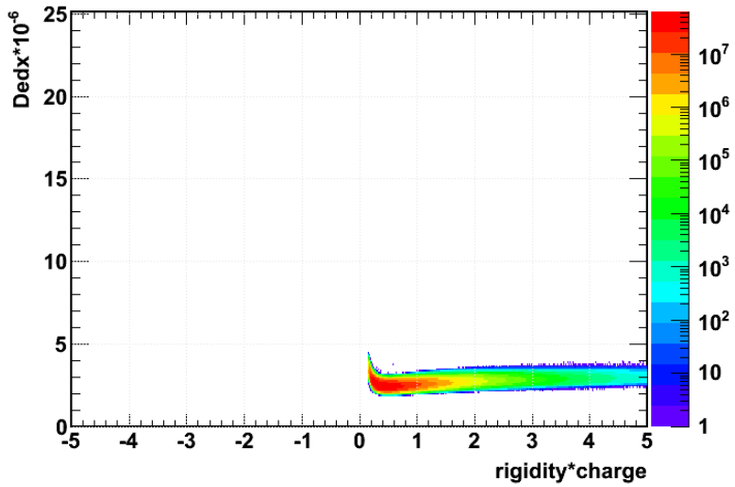
- The $v_3(\pi)/\Delta v_3(\pi)$ as a function of A_{ch} has been studied in AuAu and UU collisions. The trend of $\Delta v_3(\pi)$ slope is similar to that of $\Delta v_2(\pi)$ slope. However, the magnitude of the slope is smaller and is negative in most centrality bins.
- The same linear relationship between v_2 of $\pi^{\pm}$ and A_{ch} has been confirmed in minimum bias, UU collisions, which is consistent with CMW expectations
- More statistics are needed to study the slope of $\Delta v_2(K)$.

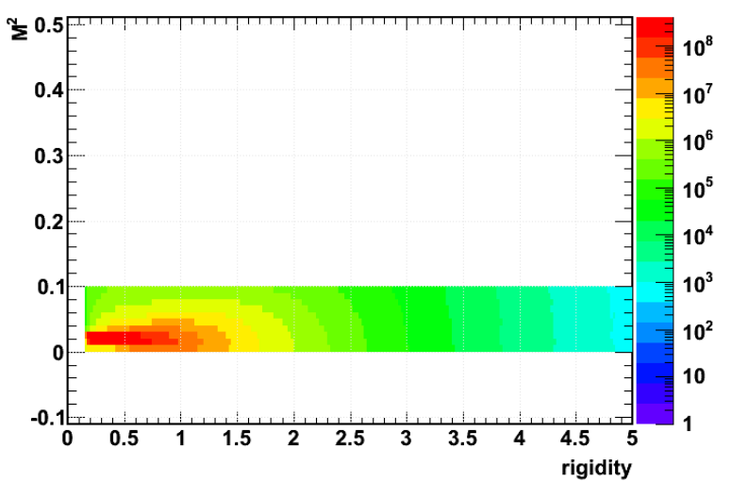
Thank you for your attention

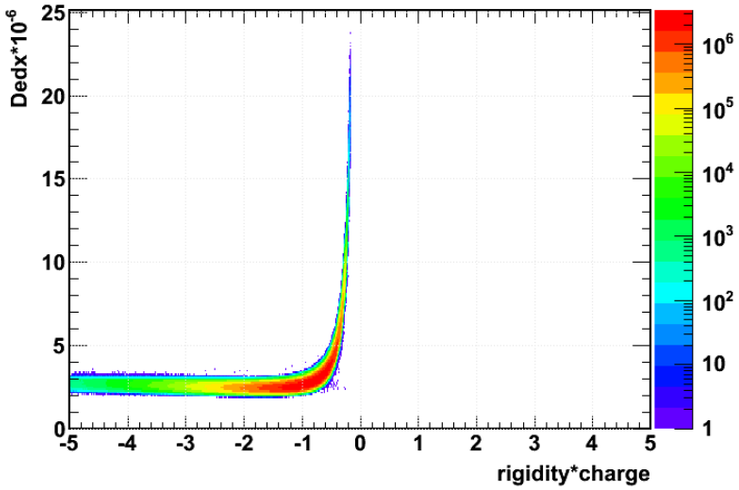
Backup

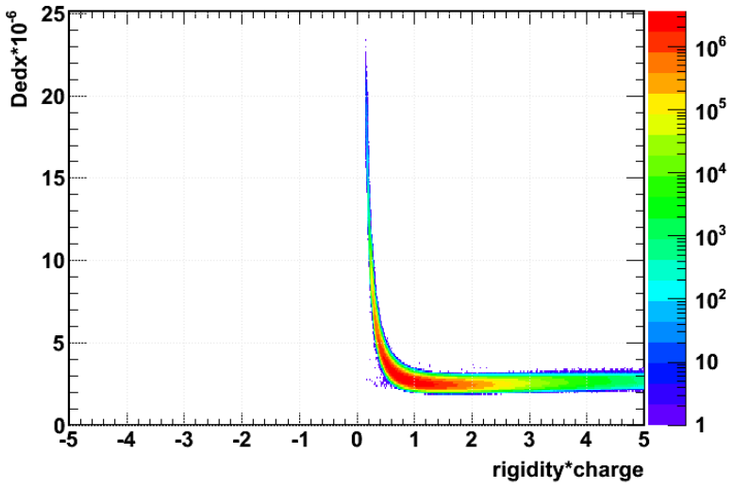
TPC/TOF Particle Identification

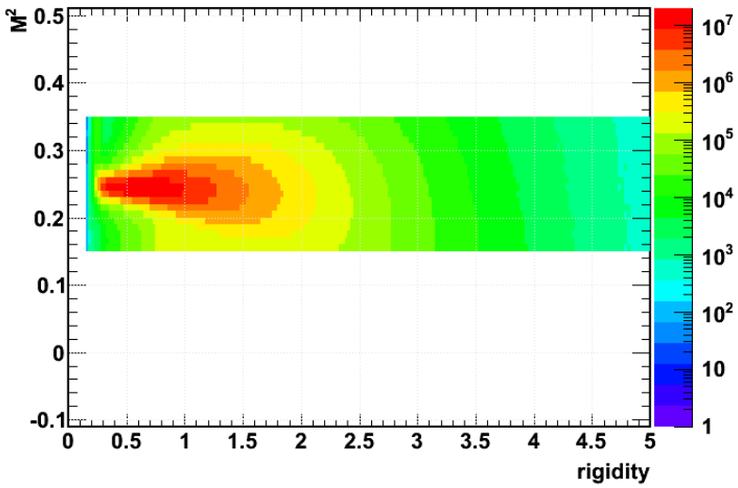




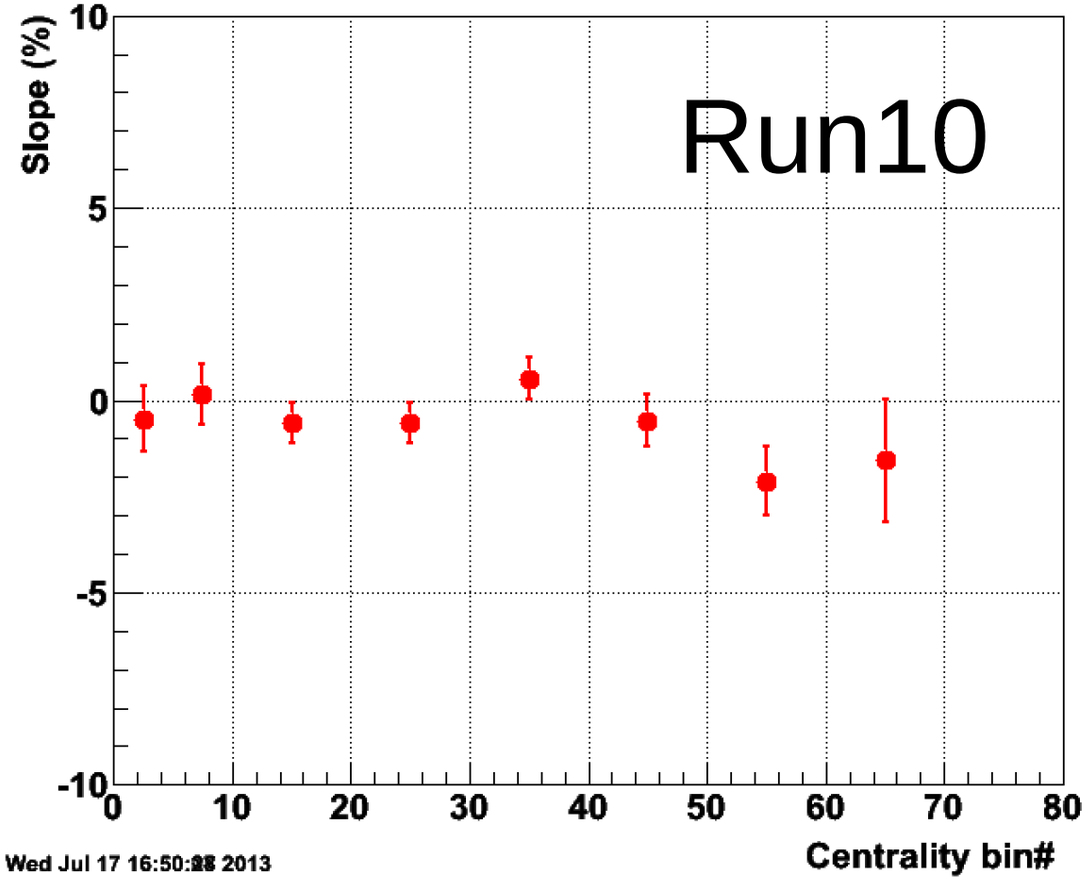


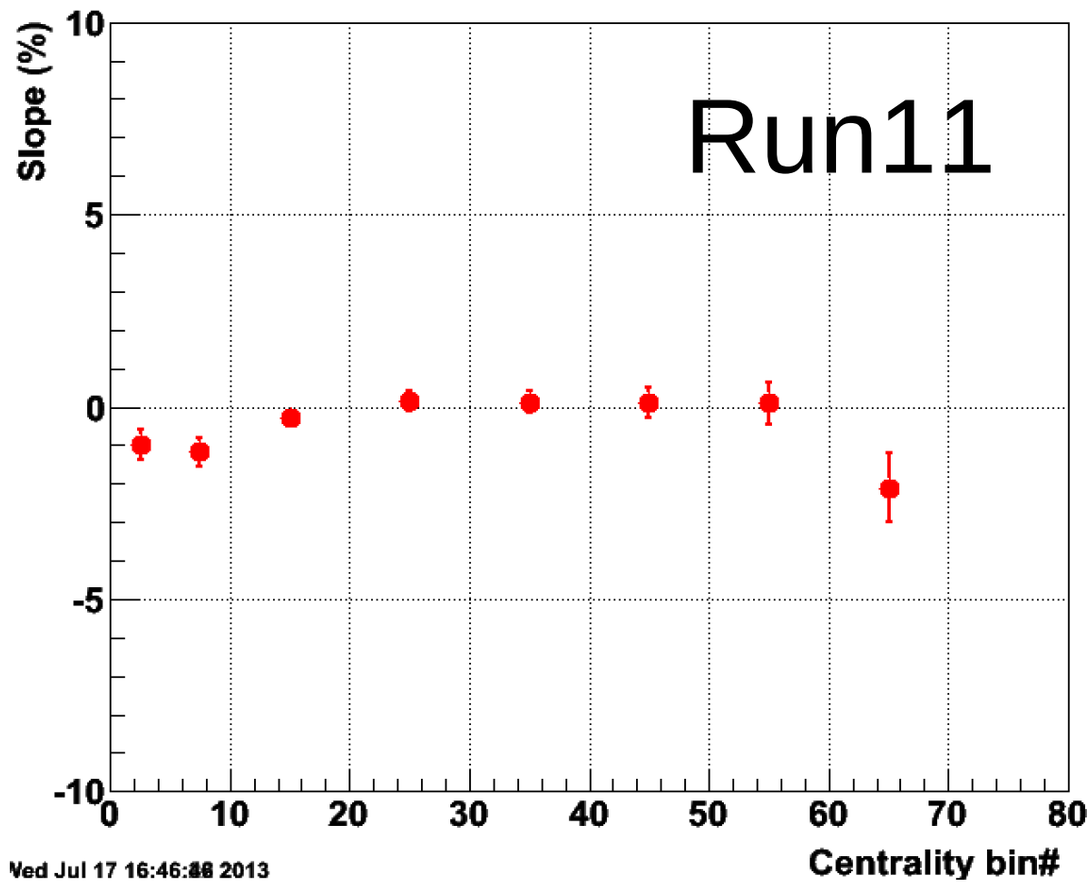




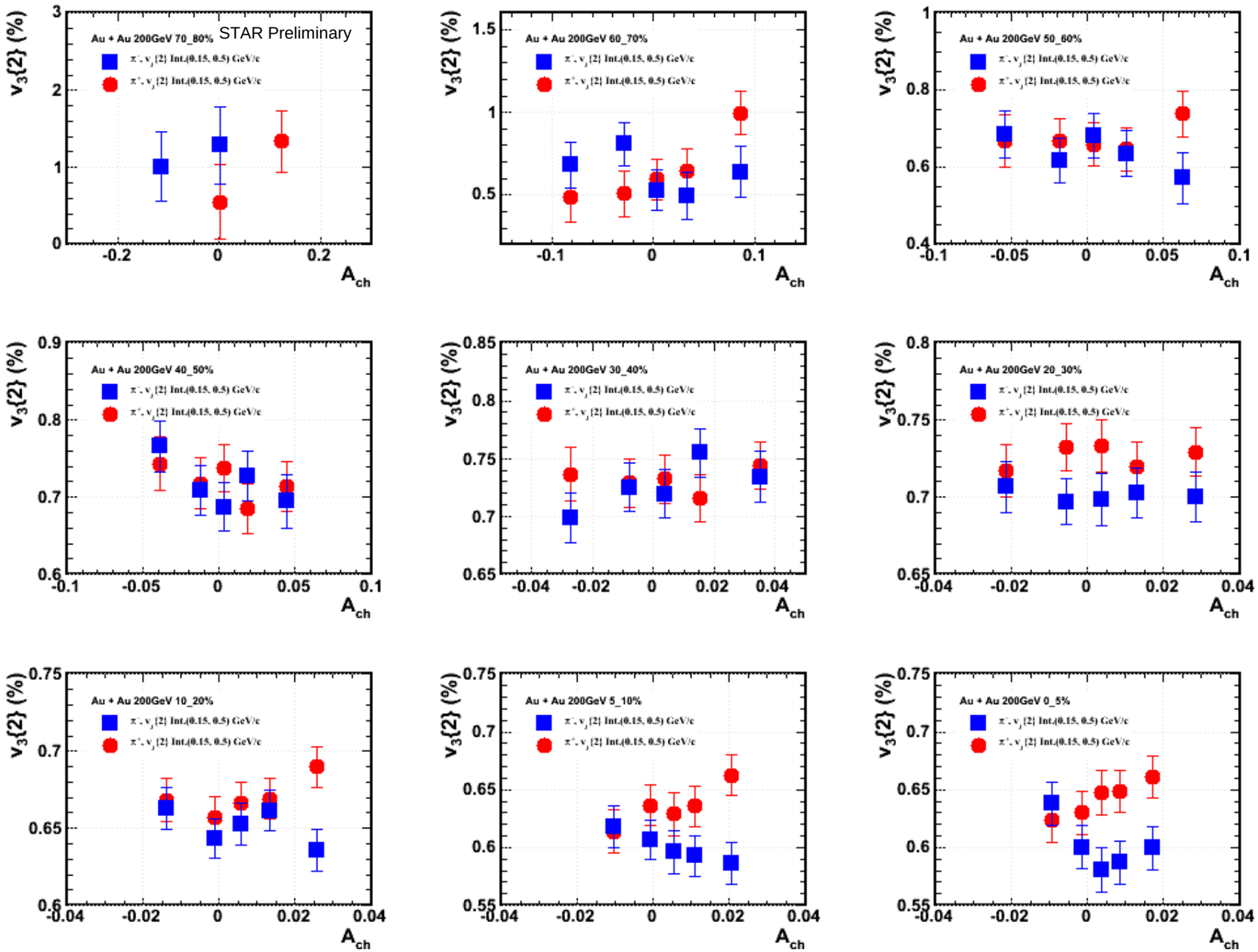


$\Delta v_3(\pi)$ vs A_{ch} Slope Before Correction in Run10 & Run11

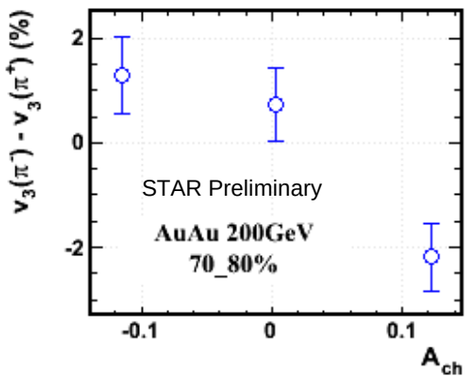


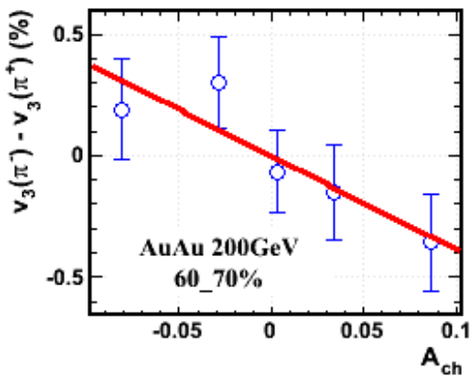


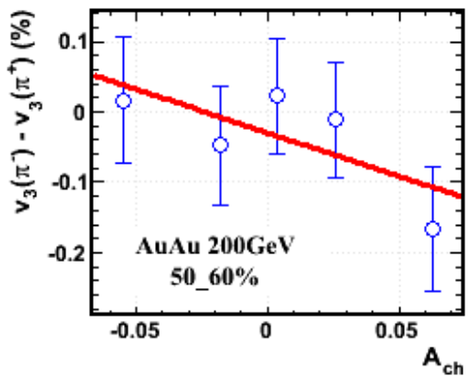
$v_3(\pi)$ vs A_{ch} in AuAu Collision

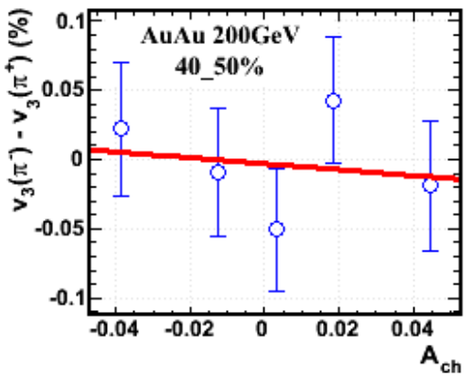


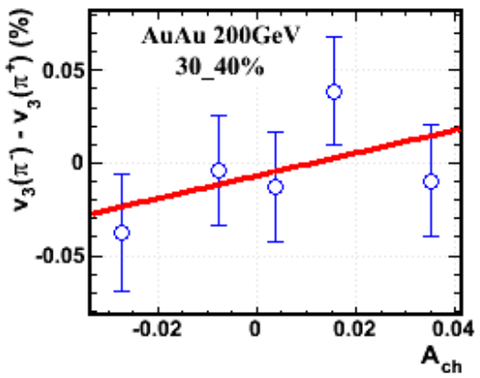
$\Delta v_3(\pi)$ vs A_{ch} in AuAu Collision

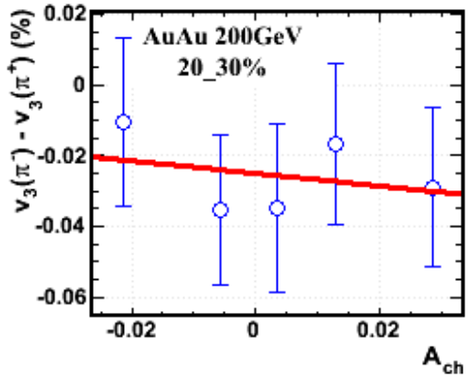


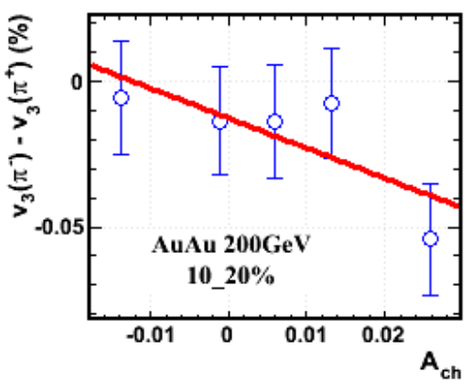


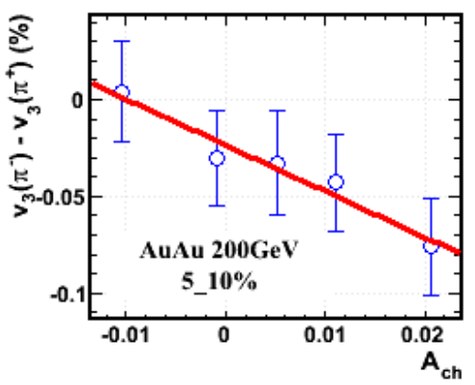


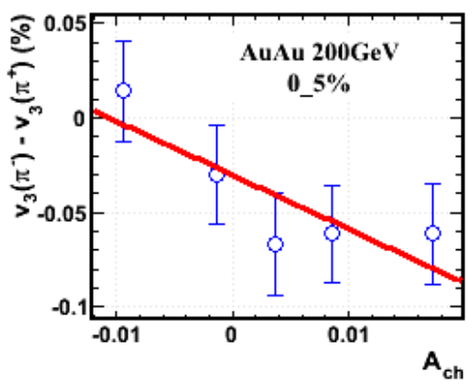




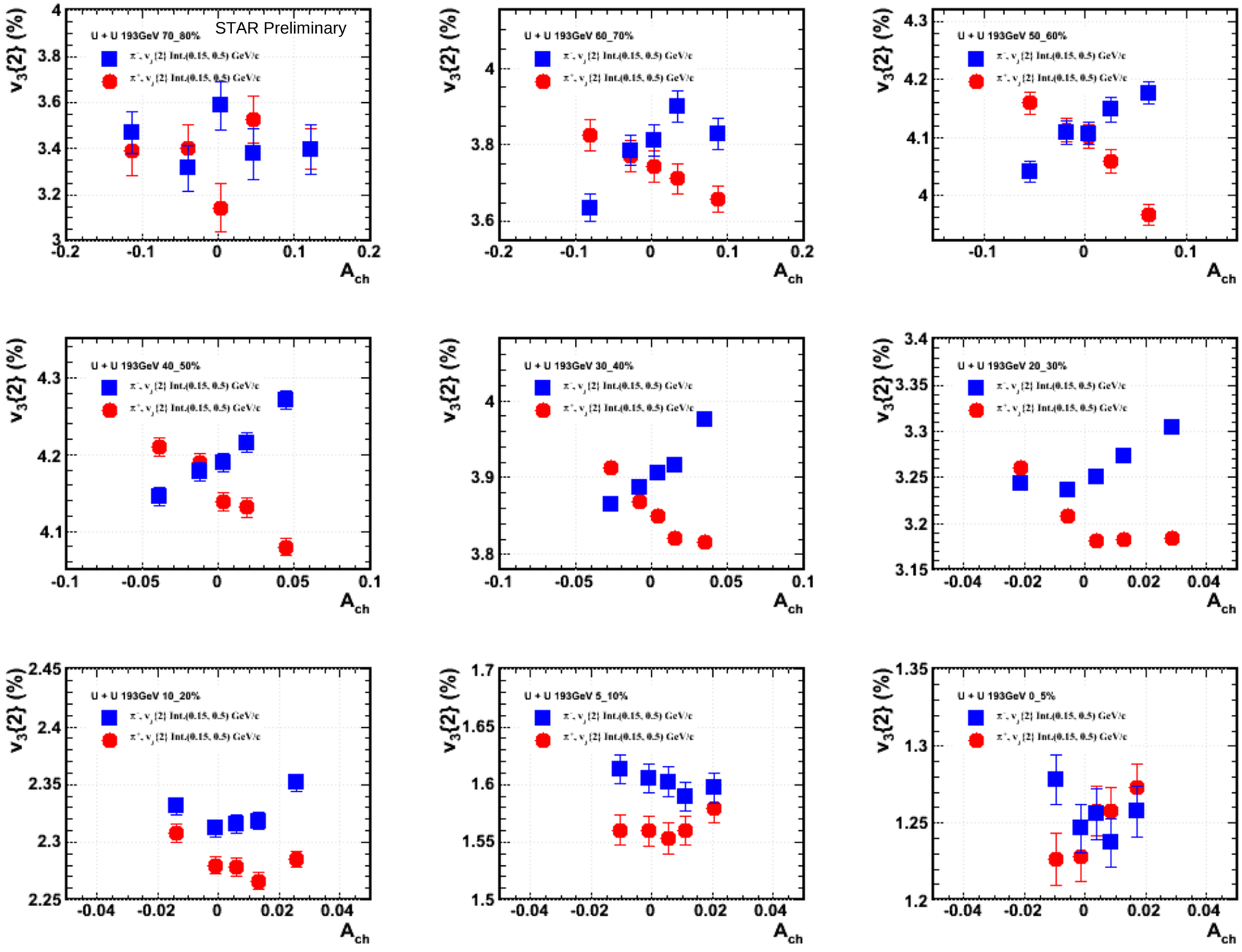








$v_2(\pi)$ vs A_{ch} in UU Collision



$\Delta v_2(\pi)$ vs A_{ch} in UU Collision